

# The processes $\gamma\gamma \rightarrow \gamma\gamma, \gamma Z, ZZ$ .

G.J. Gounaris

*Department of Theoretical Physics, Aristotle University of Thessaloniki,  
Gr-54006, Thessaloniki, Greece.  
E-mail: gounaris@physics.auth.gr*

(Collaboration with J. Layssac, P.I. Porfyriadis and F.M. Renard.)

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## Abstract

The Standard Model contributions to the processes  $\gamma\gamma \rightarrow \gamma\gamma, \gamma Z$  and  $ZZ$  at sufficiently high energies, are found to be helicity conserving and almost purely imaginary. This is due to the  $W$ -loop contribution, which is much bigger than the fermionic ones at such energies. Thus the structure of these amplitudes acquires an impressive simplicity at high energies. Nothing like this appears in other process like *e.g.* the the production of a pair of neutral Higgs bosons.

*Key words:* Standard Model, Photon, Collider,  $Z$

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The number of helicity amplitudes that can in principle contribute to the processes  $\gamma\gamma \rightarrow \gamma\gamma, \gamma Z, ZZ$  is quite large, due to the spin=1 nature of the four particles involved. In the Standard Model (SM) these processes receive no tree level contributions, thus getting their lowest order amplitudes from 1-loop diagrams involving either quarks and charged leptons, or  $W$ -bosons. At energies below *e.g.*  $\sim 250\text{GeV}$ , and for sufficiently large scattering angles so that the perturbative 1-loop calculation to be reliable, the various possible helicity amplitudes for these processes are more or less on the same footing. The situation considerably simplifies though at high energies; *i.e.* at  $\sqrt{s} \gtrsim 250\text{GeV}$  for  $(\gamma\gamma \rightarrow \gamma\gamma, \gamma Z)$ , and at  $\sqrt{s} \gtrsim 300\text{GeV}$  for  $ZZ$  production. At such energies the  $W$ -loop contribution completely dominates the fermionic one; and only the two helicity conserving amplitudes  $F_{++++}$  and  $F_{+--+}$  remain important<sup>1</sup>. Moreover, these predominant amplitudes are almost purely imaginary. This can be seen for  $\gamma\gamma, \gamma Z$  and  $ZZ$  production from Figs.1, 2 and

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<sup>1</sup> Together of course with those related to it by CP transformations and Bose statistics.

Fig.3 respectively [1], [2], [3], [4]. Please note that the amplitudes not listed in these figures are at most comparable to the smallest among the listed ones.

The physical reason for the dominant amplitudes becoming almost purely imaginary at very high energies is not particularly clear. For some reason, it turns out that the Sudakov-like  $\log^2$  terms always cancel at high energies, and only the single-log imaginary terms remain, and these for the helicity conserving amplitudes only. We have also looked at the SM contribution to the  $\gamma\gamma \rightarrow h^0 h^0$ , where  $h^0$  is the SM Higgs particle, as well to  $\gamma\gamma \rightarrow A^0 A^0$  ( $A^0$  being the CP odd Higgs particle in SUSY models), and no particular dominance for the imaginary parts of any amplitudes was observed [5].

Concerning in particular the results in Fig.3 for  $ZZ$  production, we should remark that they only apply for the light Higgs case. In that figure  $m_h \sim 100\text{GeV}$  is used, which should, be responsible for the tiny  $F_{++00}$  amplitude. For Higgs masses at the TeV scale, the importance of  $F_{++00}$  amplitude should obviously increase.

Thus, at high energies and for a small mass of the lightest Higgs, the processes ( $\gamma\gamma \rightarrow \gamma\gamma, \gamma Z, ZZ$ ) acquire a striking simplicity, at high energies. The corresponding un-polarized cross sections, integrated in the range  $30^\circ \leq \vartheta^* \leq 150^\circ$  are shown by the solid lines in Figs.4, 5, 6. Notice that in deriving these results  $\alpha = 1/128$  has been used. If  $\alpha = 1/137$  is thought more appropriate, then the results for the cross sections should be multiplied by  $\sim 0.76$ . In any case, such cross sections for unpolarized as well as for polarized beams<sup>2</sup> should be measurable if a  $\gamma\gamma$  Collider ( $LC_{\gamma\gamma}$ ) is ever built with the anticipated Luminosity [6], [7].

The aforementioned effect should be useful in searching for New Physics (NP) in an  $LC_{\gamma\gamma}$ . Please notice, that in order to get appreciable interference between the NP effect to ( $\gamma\gamma \rightarrow \gamma\gamma, \gamma Z, ZZ$ ) and the predominantly imaginary and helicity conserving SM amplitudes, we always need to be above the threshold for their direct production. Thus in [2], [3], [4] we have explored the possibility to use the above processes in order to get additional independent information that should help identifying the nature of possible SUSY candidates, that may also be directly produced. In this respect, it should be remarked that the virtual effects induced by the various SUSY particles depend on different sets of parameters than those affecting their decay. We have found that the experimental study of  $\gamma\gamma \rightarrow \gamma\gamma, \gamma Z, ZZ$  may be particularly useful for chargino-type candidates, provided their mass is  $\lesssim 200\text{GeV}$ . This can also be guessed from Figs.4, 5, 6 in which the chargino effect is always the biggest among those induced by possible SUSY candidates.

Another use, particularly of the process  $\gamma\gamma \rightarrow \gamma\gamma$ , which has repeatedly ap-

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<sup>2</sup> See [2], [3], [4].

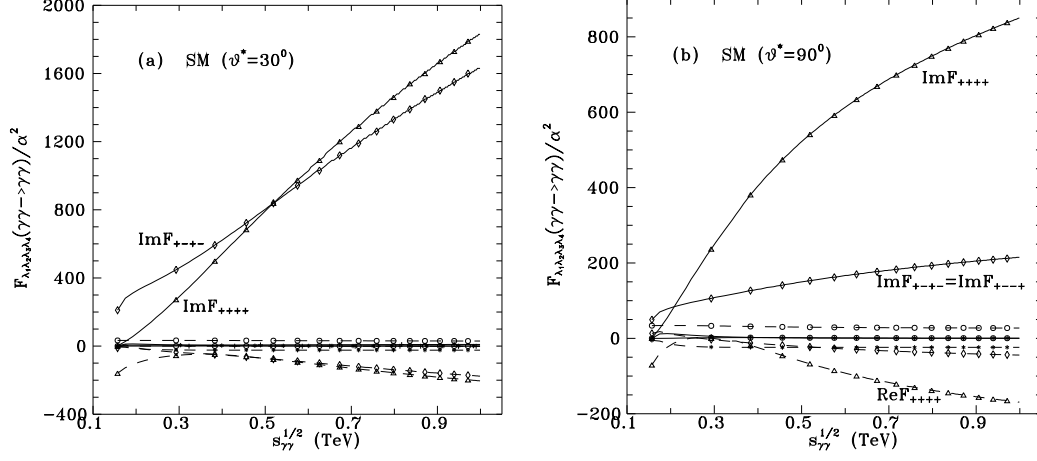


Fig. 1. SM contribution to the  $\gamma\gamma \rightarrow \gamma\gamma$  helicity amplitudes at  $\vartheta^* = 30^\circ$  and  $\vartheta^* = 90^\circ$ . Solid (dash) lines describe Imaginary (Real) parts respectively.

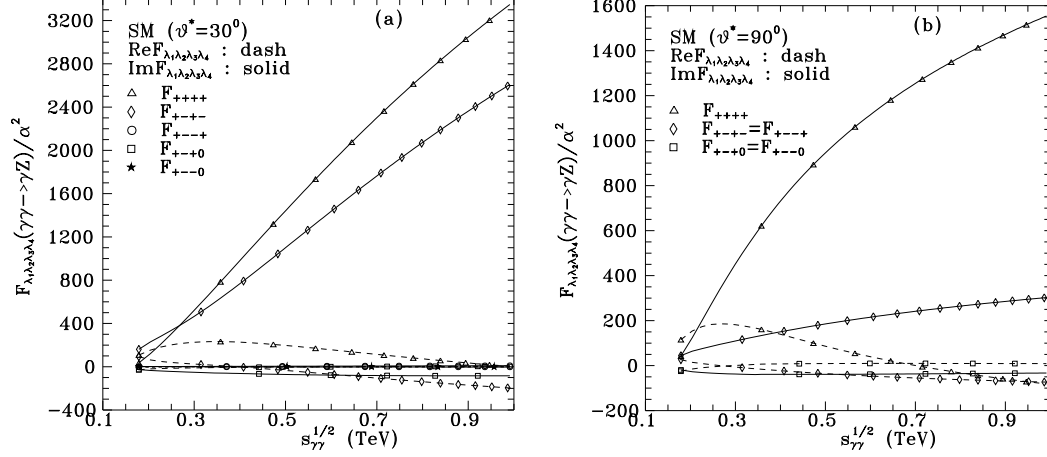


Fig. 2. SM contribution to the  $\gamma\gamma \rightarrow \gamma Z$  at  $\vartheta^* = 30^\circ$  and  $\vartheta^* = 90^\circ$ . Solid (dash) lines describe Imaginary (Real) parts respectively.

peared in the recent literature, is in order to look for effects due to strings of gravitons exchanged between the photon pairs, in case extra large dimensions might exist. Unfortunately, since this NP contribution is mainly real, there is no appreciable NP-SM interference, and the NP effect is mainly sensitive to the square of the NP amplitude. In spite of this, the quoted sensitivity appears appreciable [8]

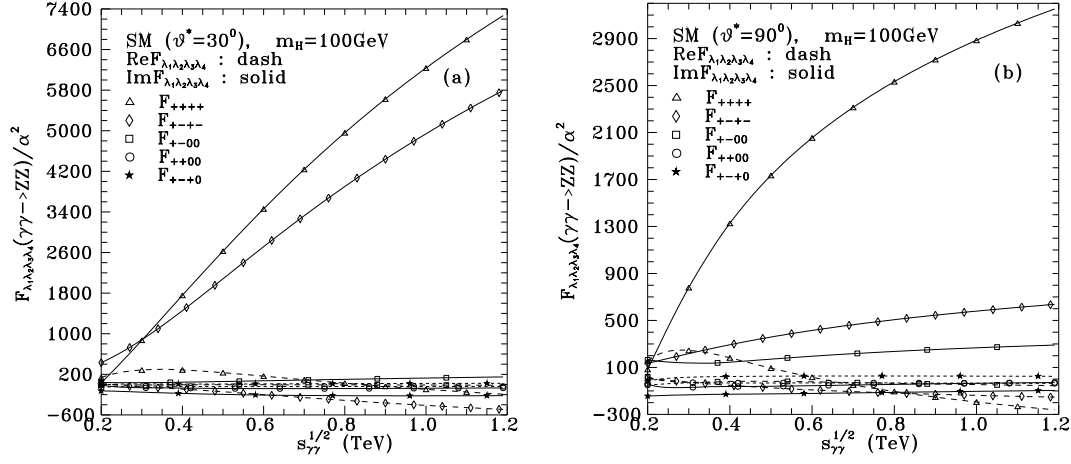


Fig. 3. SM contribution to the  $\gamma\gamma \rightarrow ZZ$  helicity amplitudes at  $\vartheta^* = 30^\circ$  and  $\vartheta^* = 90^\circ$  for  $m_H = 100\text{GeV}$ . Solid (dash) lines describe Imaginary (Real) parts respectively.

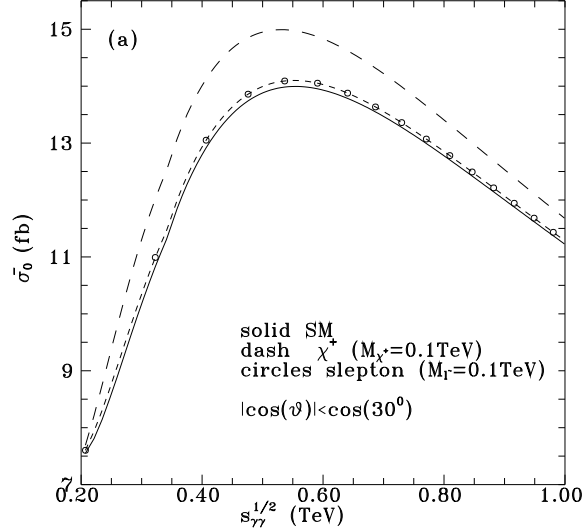


Fig. 4. SM (solid) and the effect of including various SUSY (dash) contributions to the unpolarized  $\gamma\gamma \rightarrow \gamma\gamma$  cross section integrated for center of mass angles  $30^\circ \leq \vartheta^* \leq 90^\circ$ .

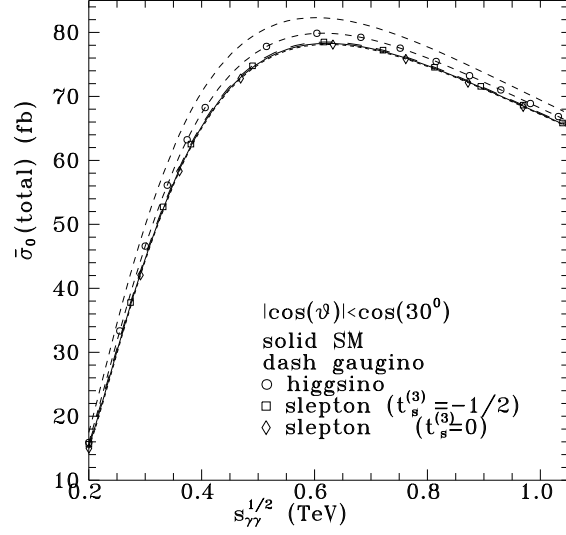


Fig. 5. SM (solid) and the effect of including various SUSY (dash) contributions to the unpolarized  $\gamma\gamma \rightarrow \gamma Z$  cross section integrated for center of mass angles  $30^\circ \leq \vartheta^* \leq 90^\circ$ .

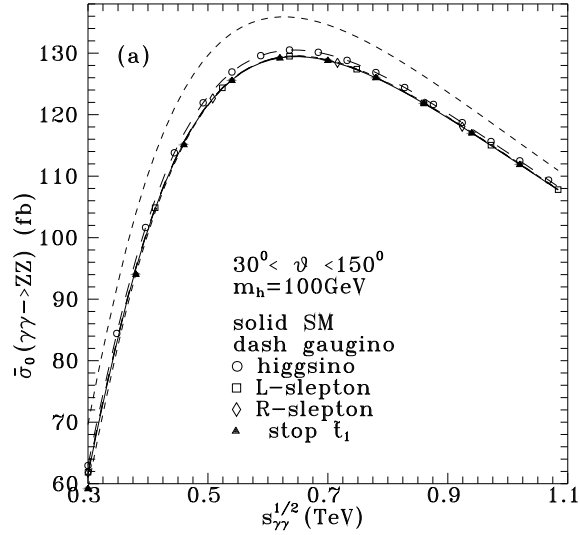


Fig. 6. SM (solid) and effect of including various SUSY (dash) contributions to the unpolarized  $\gamma\gamma \rightarrow ZZ$  cross section integrated for center of mass angles  $30^\circ \leq \vartheta^* \leq 90^\circ$ . The parameters entering the Higgs pole contribution are chosen in the decoupling SUSY regime.

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